Seabed Variability and its Influence on Acoustic Prediction Uncertainty

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LONG-TERM GOALS

Assess uncertainty in the tactical naval environment, with specific reference to geoacoustics by:

1. Characterization of seafloor variability in shelf environments
2. Assessment of the impact of seafloor variability on acoustic prediction uncertainty.

OBJECTIVES

1) Determine the uncertainty in the geoacoustic properties of the seafloor by assessing how natural variability in environmental parameters drive seabed predictive models such as *2DSedFlux*. These parameters include long-term variations in ocean climate, sediment supply and sea level. Of interest is how this variability couples with, or is independent of, numerical uncertainty in predicting the properties of the seafloor.

2) Provide *2DSedFlux* realizations in areas of interest to the seafloor geoacoustic team (Pratson, Holland). The *SedFlux* realizations provide data sets for seismic convolution experiments (Pratson), inverse experiments (Holland), propagation experiments (Odom) and reverberation experiments (LePage). *SedFlux* simulations provide information on seafloor layering (bed coherency, bed attributes: grain size, bulk density, porosity, permeability).

3) Apply these uncertainty-modeling techniques to the ONR-Geoclutter Modeling group investigating false-target acquisition due to buried channels.

4) Determine which continental margins would/could experience seasonal or inter-annual changes in the nature of its seafloor properties through the impact of events (earthquakes, ocean storms, river floods).

APPROACH

1) Characterize the natural variability of the environmental forces controlling the seabed at the selected sites.

2) Conduct a series of *SedFlux* realizations of seafloor attributes to capture the natural variability of the modern climatology, and then show how the seafloor properties would change under climate change scenarios (wetter, drier, hotter, colder). Here the emphasis is on both spatial and temporal changes in the seafloor properties.

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3) Provide Geoclutter Modeling team, *SedFlux* realizations to characterize the New Jersey margin, where buried channels impact the sub-seafloor acoustic response.

4) Using SedFlux, conduct experiments to determine the impact of single events (e.g. a large 100yr flood) on the seafloor characteristics. Determine the magnitude of the change in the seafloor character, and develop a method to provide this information in some probability density function.

WORK COMPLETED

1) Assessment of environmental parameters and their influence on the predicted stratigraphy
Completed the assessment of the geological boundary conditions and their influence on the predicted stratigraphy for the New Jersey margin. Twenty sensitivity experiments were run at very high resolution (time step: 1d, vertical resolution: 10cm) to explore a wide range of best-scenario environmental conditions. State-of-the-art proxies for climate, storminess, and glacier melt water flow were used for the first time in our modeling framework. Realizations are posted in our ftp site.

2) Developed an "expert system" to retrieve boundary conditions on a global scale
The New Jersey site study provides us with a pathway in collecting appropriate environmental parameters. Many parameters are retrieved from global datasets (e.g. Hydro1K Digital Elevation Model, Community Climate Model 1: Fig. 1, Glaciological Model), which are equally valid for new proposed study sites (i.e. the Malta Channel). Global databases of topography, bathymetry and climate data, which were used for the NJ study, are now mined for Italian sites. Similarly, we use the NCAR-CCSM Climate Model output to acquire paleo-climate data. Local information supports the global databases. Based on the sequence stratigraphic units as described in 'A High Resolution Seismic Sequence Analysis of the Malta Plateau' by Osler & Algan (SACLANTCEN SR-311) we have conducted an initial detailed run of ~18,000 year, incorporating seismic units 1, 2 and 3 with a maximum sediment thickness of about 70 m. Vertical resolution is 0.1 m. Sensitivity experiments incorporate 3 different (but closely spaced) initial bathymetries, reconstructed from the isopach maps of the seismic units.

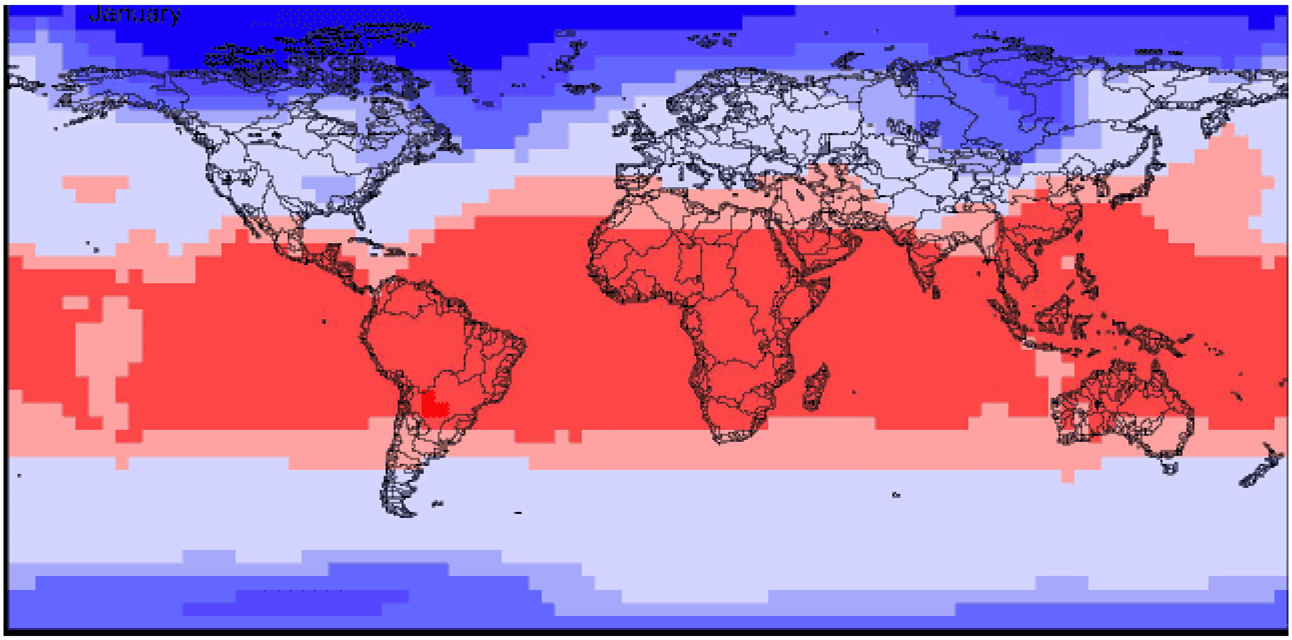

Figure 1: Example of NCAR-CCSM climate simulation (T°C) simulation at 21 kyr that provides temperature and precipitation values for combined HydroTrend – SedFlux simulations.

3) *SedFlux* predicts volume fractions of grain size distribution

To improve the translation of *SedFlux* seafloor properties to acoustic properties, *2DSedFlux* now generates the volume fraction of the simulated grain size classes (Fig. 2). This is an important requirement for the Biot model that Pratson (Duke U) uses to determine acoustic properties.

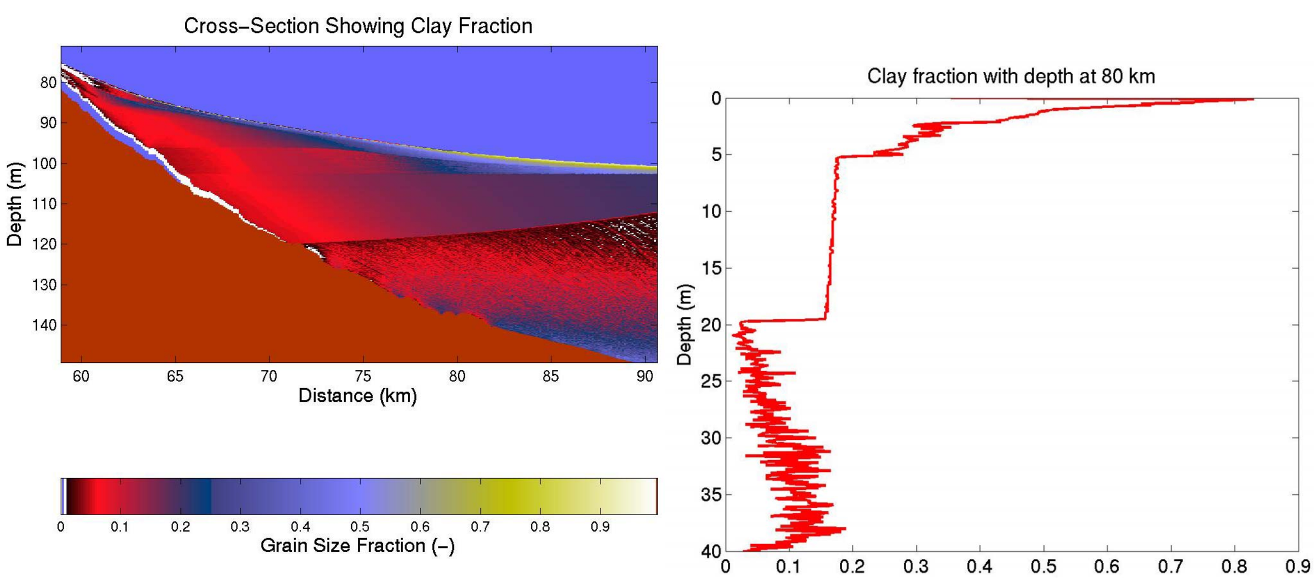

Figure 2: Example of grain size volume fraction output of SedFlux, New Jersey Outer Shelf wedge consist of coarse sediment (low clay fraction) up to the uppermost 5 m.

RESULTS

The assessment of the geological boundary conditions and their influence on the predicted stratigraphy for the New Jersey margin provides us with the first attempt beyond the common practice in sedimentary modeling to only present the 'best-guess' scenario. We have demonstrated through a climate-driven model *HydroTrend* that paleo-drainage area, paleo-temperatures, paleo-precipitation strongly influence the discharge and sediment loads delivered to the ocean. The uncertainties in the estimates for these parameters can be significant – a factor of 2 is not exceptional. River loads are an important driving force in the *SedFlux* model and in building the offshore stratigraphy. However, net changes in the environmental parameters do not linearly propagate into the predictions of the seafloor properties. The 'base-case or best-guess' *SedFlux* prediction for the sedimentary architecture of the New Jersey shelf is consistent with the acoustically observed thickness distributions and facies (Fig. 3). Sensitivity tests that explore the realistic ranges in the input parameters show local deviations in the thickness distribution of up to 46%, considerable depth variation (>10m) in the prediction of certain facies shifts and up to 1.5Ø difference in the mean grain size prediction.

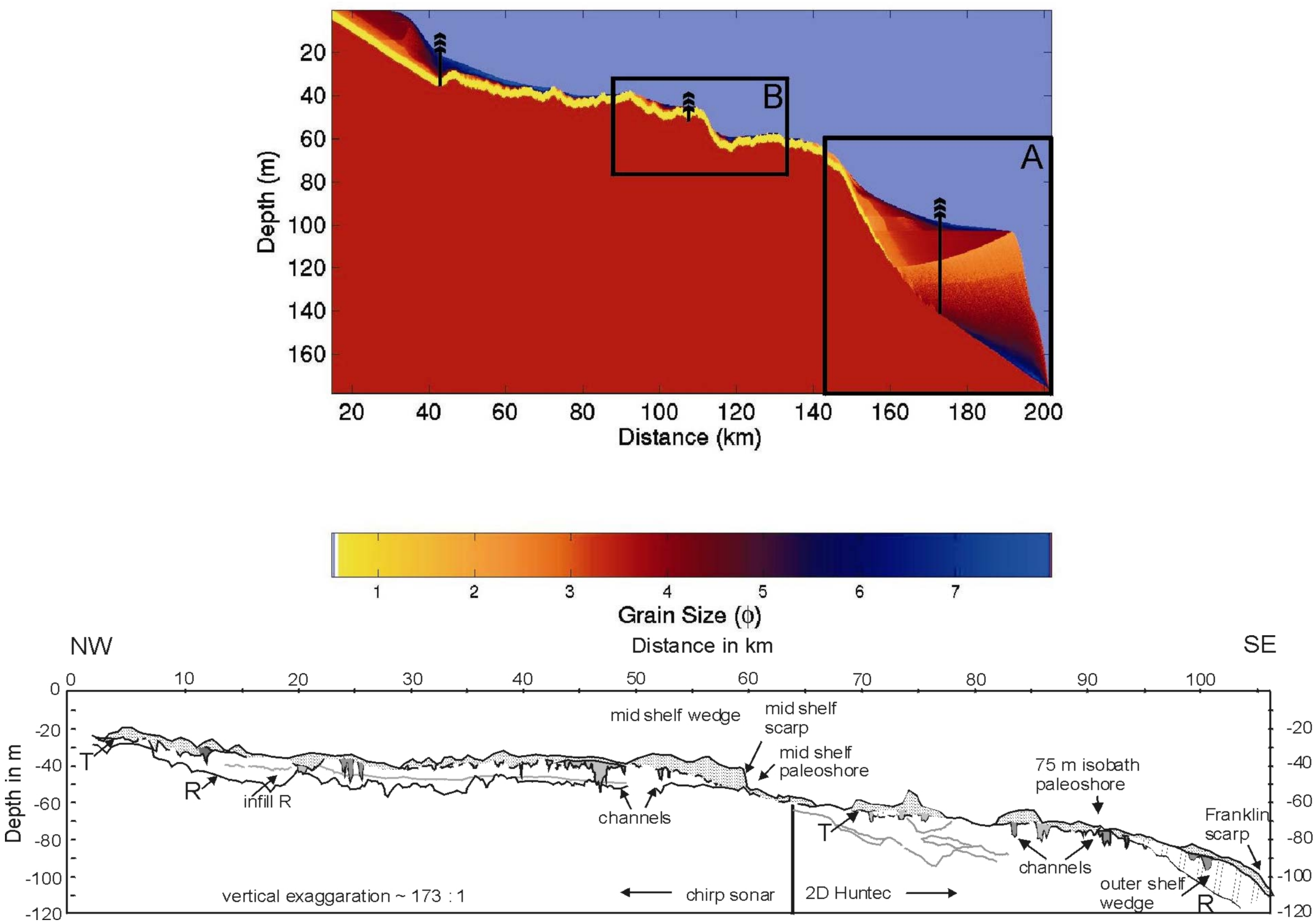

Figure 3. Top: 'Base-case' SedFlux prediction for the sedimentary architecture of the New Jersey shelf is consistent with acoustically observed thickness distributions and facies. Bottom: Schematic of dip profile showing the shallow stratigraphy of the New Jersey margin based on chirp sonar profiles landward of the ~50m isobath and Huntec boomer profiles from ~50-100m (after Duncan et al., 2000).

Two main attributes are proposed to quantify uncertainty in environmental parameters and comparing how changes in sea floor properties based on these attribute variations. The first, the *geometric attribute,* is the thickness distribution (TH) of the deposit. The range in TH characterizes can be compared to bathymetric, seismic and borehole data. For that reason, TH attributes are useful as a calibration or goodness-of-fit criterion.

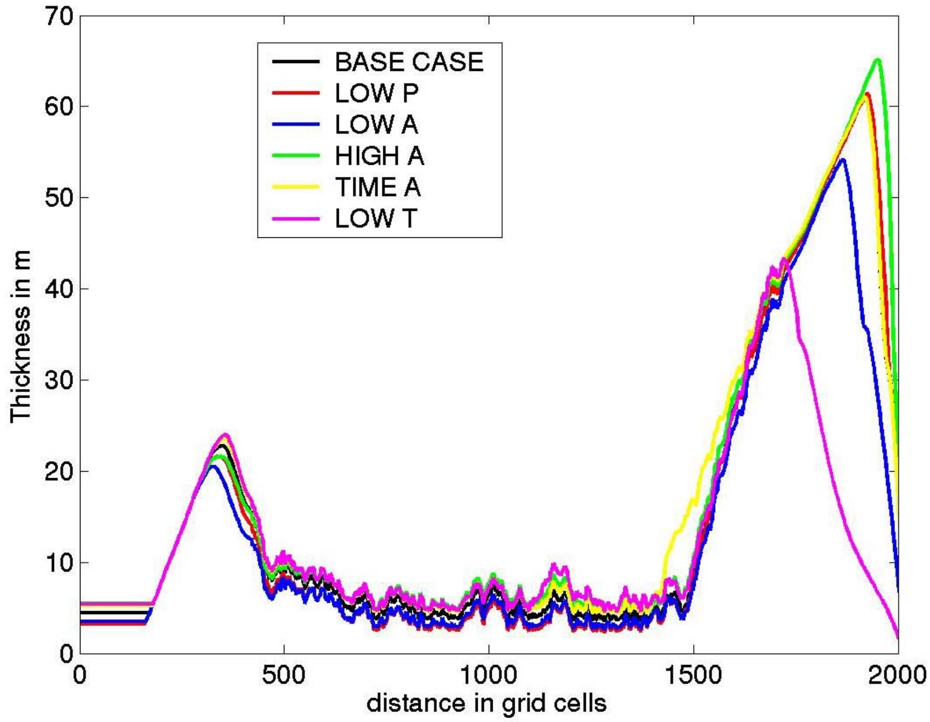

Figure 4. Range of SedFlux predictions of the thickness of the deposited sediment on the New Jersey margin (river mouth is grid cell 200, shelf edge is 2000; 1 cell=100m). Scenarios include large and small drainage areas (HIGH A, LOW A), lower precipitation (LOW P), ice age temperature (LOW T), and delay in ice sheet melting (TIME A) on the difference in the thickness of the deposited layer.

The second uncertainty measure is the *depth attribute*: variation in sea floor properties with depth at a fixed position: grain size, permeability, porosity and density. Figure 5 shows an example of a pseudo well in the middle shelf region of New Jersey, based on two sensitivity runs with distinctly different ocean storm regimes. Under a low-energy regime, the grain size variation in depth below the seafloor is very limited (within 1Ø), whereas a high-energy regime transports coarser sediment into the offshore and winnows out the fines, and the sediment layering becomes pronounced. Uncertainty in boundary conditions certainly can also be studied. Site predictions can be assessed as standard deviation (Fig. 6) of properties based on a series of sensitivity tests. The more complete the boundary domain is known the better will be the variability measure. Predictions of stratigraphy are most valuable if associated with a measure of the range of outcomes from sensitivity experiments.

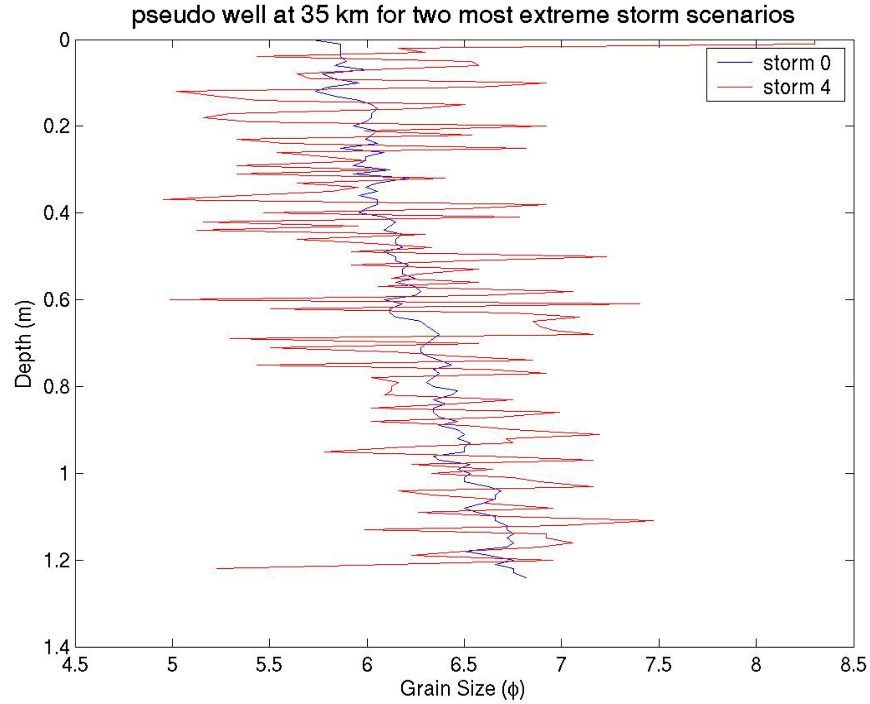

Figure 5. A pseudo well at 35 km offshore from the river mouth shows effect of storm events on grain size layering. High storm regime (storm 4) sort sediment into layers, by transporting shallow water coarser sediment offshore and winnowing out fine sediment.

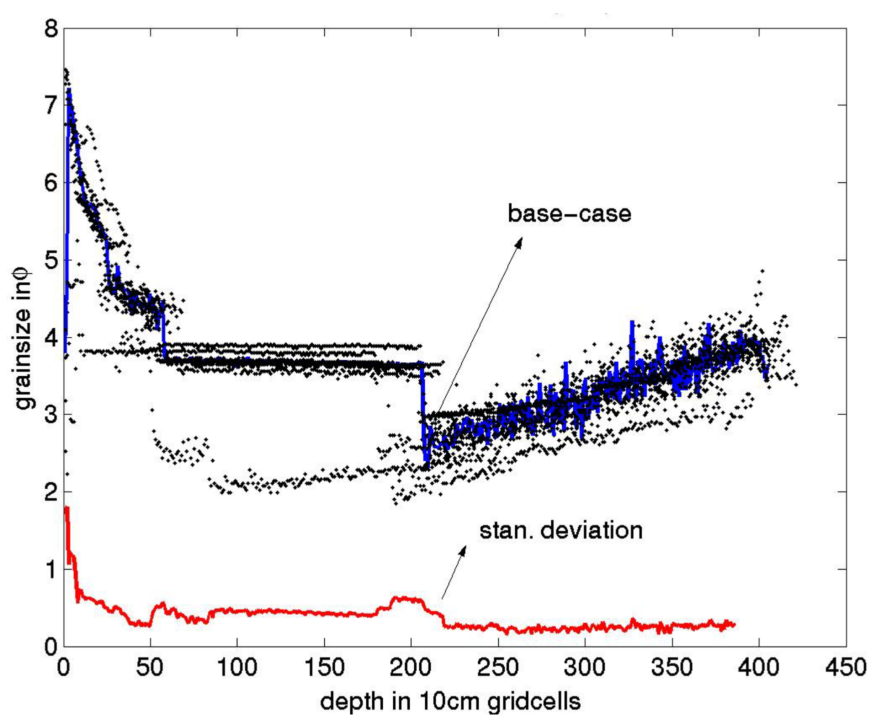

Figure 6. Predicted grain size at location 170km from the present coastline of New Jersey, with variability from sensitivity scenarios shown in dots. The standard deviation of the prediction is based on sensitivity tests and provides a measure of the variability caused by changing boundary conditions.

IMPACT/APPLICATIONS

We developed an upscaling approach to allow the model SedFlux to provide numerical predictions of seafloor properties at a resolution which suites modern acoustic systems at low and high frequencies. Simulated event beds can be interpreted in terms of grain-size variability, permeability, density and porosity and can almost directly be compared to real event strata.

TRANSITIONS

ExxonMobil is using the SedFlux code in both reservoir characterization and as an exploration tool.

RELATED PROJECTS

ONR Geoclutter: http://instaar.colorado.edu/deltaforce/projects/geo_clutter.html
ONR EuroSTRATAFORM: http://instaar.colorado.edu/deltaforce/projects/euro_strataform.html
NSF Community Sediment Model: http://instaar.colorado.edu/deltaforce/workshop/csdms.html
NSF MARGINS: http://instaar.colorado.edu/deltaforce/projects/margins.html

PUBLICATIONS

Hutton, E.W.H. and Syvitski, J.P.M., 2003. Advances in the numerical modeling of sediment failure during the development of a continental margin. Marine Geology. *[in press, refereed]*

Morehead, M.D., Syvitski, J.P.M., Hutton, E.W.H., and Peckham, S.D., 2003. Modeling the inter-annual and intra-annual variability in the flux of sediment in ungauged river basins. Global and Planetary Change. *[in press, refereed]*

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